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TEMPERATURE-YIELD STRENGTH CORRELATION OF THE CRATER SIZE PRODUCED IN ALUMINUM BY THE HYPERVELOCITY IMPACT OF ALUMINUM SPHERES

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NOLTR 63-142

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Ballistics Research Report 108

(6) TEMPERATURE-YIELD STRENGTH CORRELATION OF THE CRATER SIZE PRODUCED IN ALUMINUM BY THE HYPERVELOCITY IMPACT OF ALUMINUM SPHERES

~~Prepared~~ by:
R. Piacesi, R. H. Waser and V. C. D. Dawson.

ABSTRACT: An investigation was made to determine the correlation between target temperature and target yield strength for the hypervelocity impact of aluminum spheres upon semi-infinite aluminum targets. It was shown that an exact correlation does exist. In the velocity range covered in the experiment (12,700 feet per second to 21,750 feet per second) the crater volume was dependent on the -.396 power of the yield strength. It was also observed that a transition region exists at an impact velocity of about 13,000 feet per second, such that the crater volume is not linearly dependent on the kinetic energy of the projectile, but that for velocities from 13,000 feet per second and up to at least 21,750 feet per second the crater volume is dependent on the velocity to the 1.78 power.

PUBLISHED MARCH 1964

U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

30 August 1963

TEMPERATURE-YIELD STRENGTH CORRELATION OF THE CRATER SIZE PRODUCED IN ALUMINUM BY THE HYPERVELOCITY IMPACT OF ALUMINUM SPHERES

This work was performed as a part of Polaris Long Range Research under Task Number PR-23.

R. E. ODENING
Captain, USN
Commander

A. E. Seigel
A. E. SEIGEL
By direction

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ILLUSTRATIONS

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LIST OF SYMBOLS

c_o speed of sound in the target

V_o projectile impact velocity

V_c volume of the crater

V_p volume of the projectile

INTRODUCTION

A prerequisite for the complete formulation of the effects of high-velocity particles impacting on a thick target is the understanding of the basic physical processes involved. Each of the large number of variables which appear to influence the resulting crater dimensions and their interdependence must be evaluated.

Although it is generally recognized that some mechanical strength property of the target and its temperature dependence is important in the cratering process, no experiments have tied down this temperature-strength correlation. An investigation was made to determine if there is an exact correlation between the target yield strength and the target temperature.

EXPERIMENT

It has generally been known that the crater size is dependent on the mechanical strength of the target. Experiments have also been conducted demonstrating that heating the target caused larger craters to result from impacts (ref. (1)). It has also been pointed out that when the temperature is varied, anomalies in the crater dimensions appear at temperatures where anomalies occur in the strength of the target material (ref. (2)). Others have shown that a favorable graphical comparison exists between the cratering efficiency and the target tensile strength as a function of temperature (ref. (3)). The question arises then, as to whether an exact correlation in crater size exists between the target temperature and a mechanical property, such as the yield strength. For example: consider cratering in two targets of the same material but different yield strengths. If the yield strength of the two targets was made equal by raising the temperature of the higher-yield strength target, would equal size craters be obtained for a given impact?

The experiment consisted of firing 1/4-inch diameter aluminum spheres into 2-inch thick, 8-inch diameter aluminum targets. The targets were of 7075-T6, 2017-T4 and 7075-0 aluminum having room temperature yield strengths of 68,500 psi. 38,500 psi and 17,000 psi, respectively. (These values were obtained from yield strength tests made on samples of the target material stock.) A range of impact velocities was covered for each of the three different targets at room temperature and the resulting craters were measured. Impacts were made on four 7075-T6 targets, two which were heated to 380°F and two to 500°F, having true yield strengths of 40,500 psi and 25,500 psi, respectively, and on one 2017-T4 target heated to 357°F having

a true yield strength of 25,500 psi. (These yield strength values were also obtained from curves constructed with data from yield strength tests made over a range of temperatures.)

The crater volume was measured with reference to the original surface using a low surface tension fluid and a hypodermic syringe. The depth was measured with a depth micrometer and the diameter was measured with an optical comparator. The correlation was made with the crater volume because of the large scatter in the depth. This scatter was due to the roughness of the craters in the more brittle 2017-T4 and 7075-T6 targets.

A log-log plot of the parameters V_c/V_p against V_o/C_o is shown in figure 1. The room temperature constant yield strength lines indicated that the V_c/V_p was dependent on the -.396 power of the yield strength at constant velocity (see fig. 2) for velocities from 12,600 feet per second to at least 21,750 feet per second. An interpolation was made for the lines of constant yield strength for the heated target conditions. The experimental temperature-yield strength correlation is seen to be very good with the exception of one point for one of the 7075-T6 targets which was heated to 380°F, in which case the point is high. It should be noted that the slope of the constant yield strength lines is not 2 but 1.78, indicating that a transition region has appeared. This would mean that we have reached a region where strength effects may be starting to diminish in importance. The one low-velocity shot into the room temperature 2017-T4 target did not fall on the 1.78 slope line and therefore was assumed to be in the kinetic energy dependent region. A line of slope equal to 2 was drawn through this point to observe where the transition point might be. The transition point for the 2017-T4 target is indicated to be at 1[illegible],000 feet per second. When the point is reached where the strength effects can be ignored, the slope should be equal to 1.0 (ref. (4)) and the lines of constant yield strength should converge into only one line. In order for the lines to converge, the transition point should occur at lower velocities in the lower-yield strength targets. A line indicating the possible transition point as a function of yield strength is shown in figure 1.

It was intended to further substantiate the temperature yield strength correlation by firing more shots into heated targets and also to investigate the transition region by firing low-velocity shots into room temperature targets. However, sabot problems which depleted the supply of target material prevented a continuation of the test at the present time. It is the intention of the authors to continue this investigation more thoroughly with a new supply of target materials.

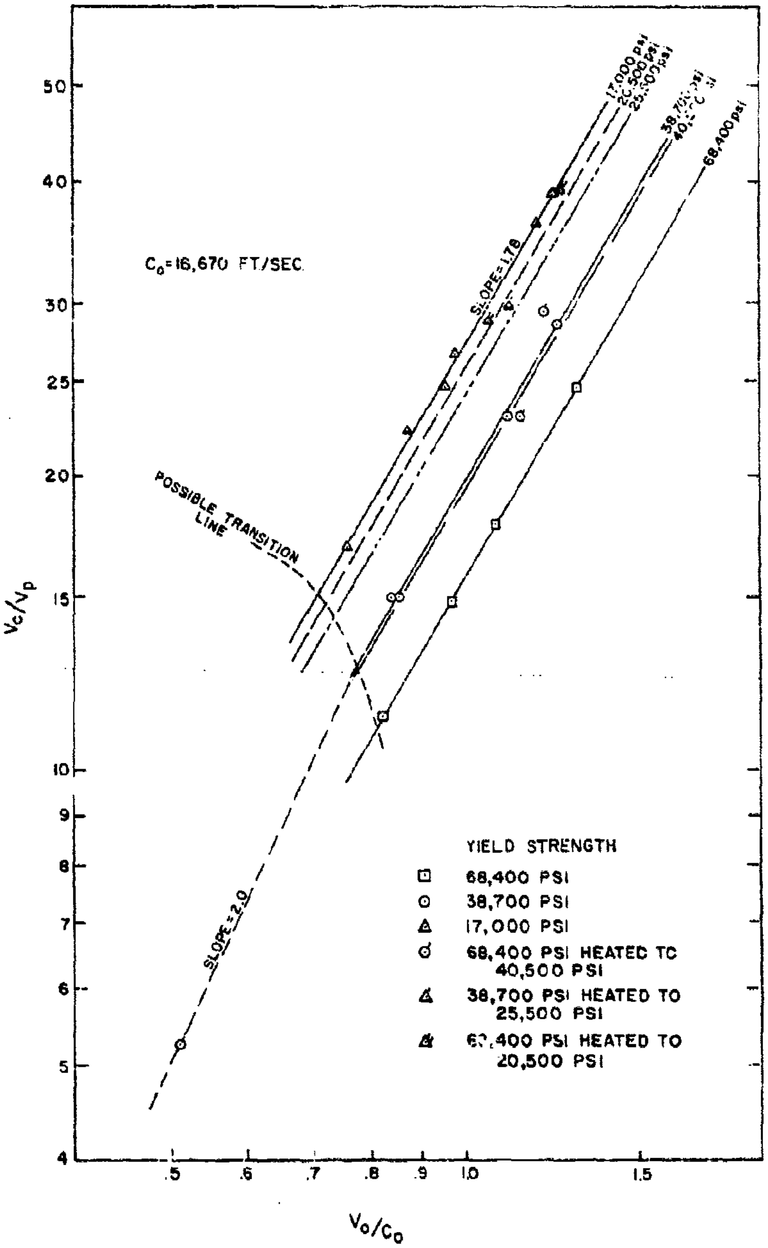
The test facility used for this program was the NOL Ballistics Range No. 2. This range is a 66-foot long, 3-foot diameter tube which can be evacuated to less than 1 mm Hg pressure and which is equipped with projectile velocity measuring instrumentation consisting of light screens and time interval counters. A Beckman-Whitley 192 high-speed framing camera and a flashtube light source were installed for this program to photograph the impact of the projectile with the test targets. A 0.500-inch two-stage light-gas gun was used to accelerate the 0.250-inch aluminum sphere projectiles to velocities up to 22,000 feet per second. Figure 3 shows the range facility setup schematically. The still camera with spark light source is associated with the velocity measuring system to provide a positive check on its operation by photographing the projectile which triggers the light screens.

For the shots in which the target was heated, a 1,000 watt electric Calrod heater was fastened to the back side of the target and temperature was monitored by making use of a thermocouple placed in a hole drilled in the target. It was experimentally determined that the temperature gradient in the target and the inaccuracy in measuring temperature amounted to no more than 3°F. Before firing, the projectiles were mounted in bore-size lexan sabots, which were stripped off and deflected as they left the muzzle of the gun. The range tube pressure in all cases was decreased to less than 2 mm Hg pressure to prevent the projectile from ablating before its impact with the target.

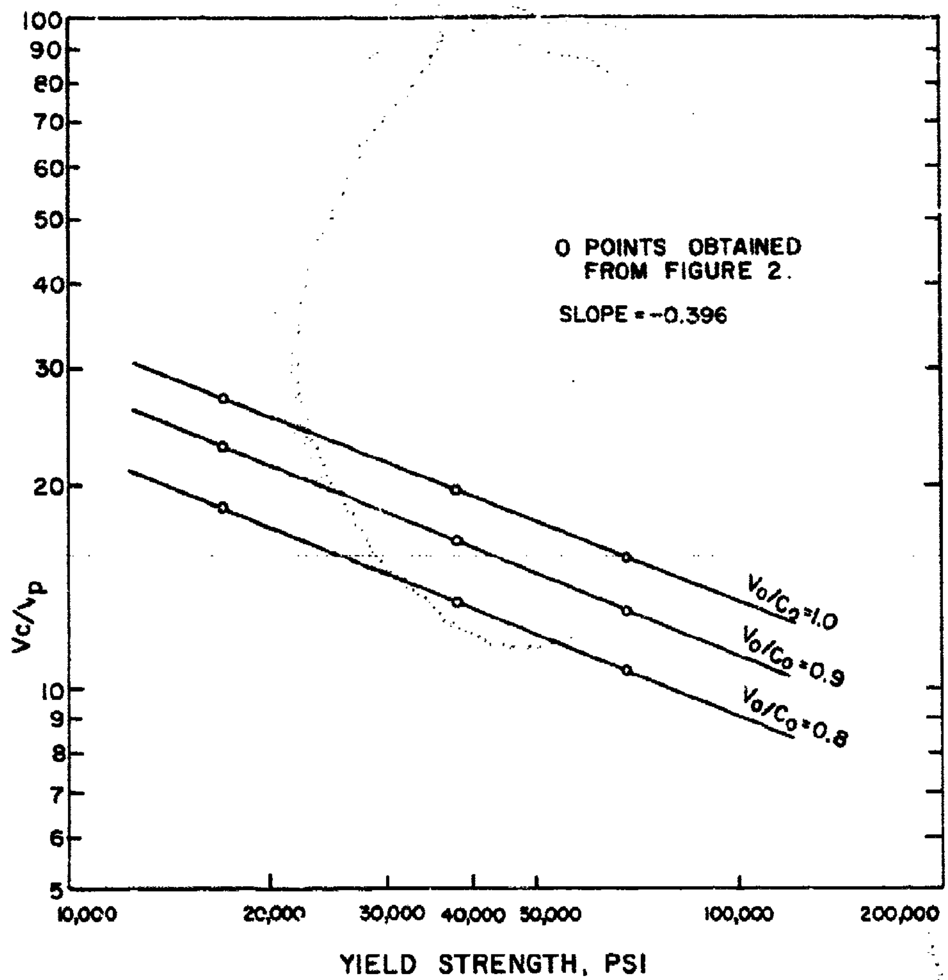
A sequence of impact pictures taken with the high-speed framing camera are shown in figure 4.

CONCLUSION

It is concluded that there is an exact correlation between temperature and yield strength. The crater volume is seen to be dependent on the -.396 power of the yield strength for impacts of aluminum spheres on semi-infinite aluminum targets in the velocity range from 12,700 feet per second to 21,750 feet per second. From a transition point at about 13,000 feet per second and up to at least 21,750 feet per second the crater volume is not dependent on the kinetic energy of the projectile but rather on the velocity to the 1.78 power, indicating that the strength effect on the cratering process may be diminishing above a velocity of 13,000 feet per second.

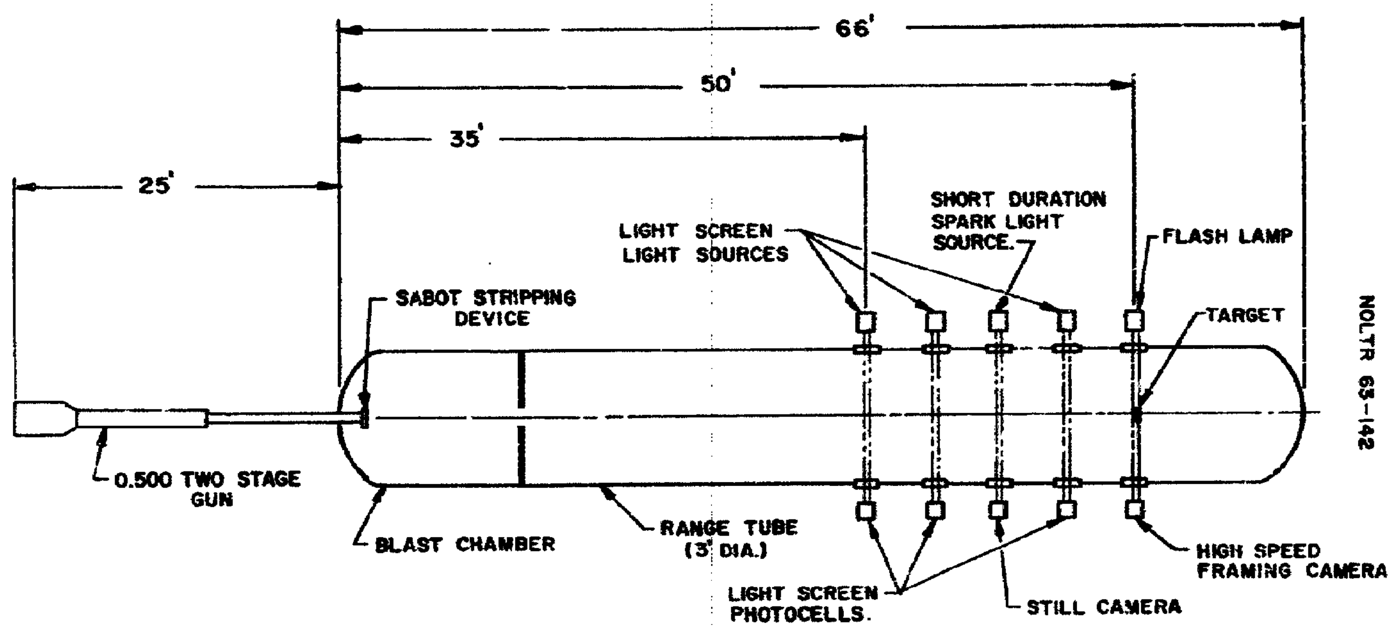


YIELD STRENGTH CORRELATION
FIGURE 1

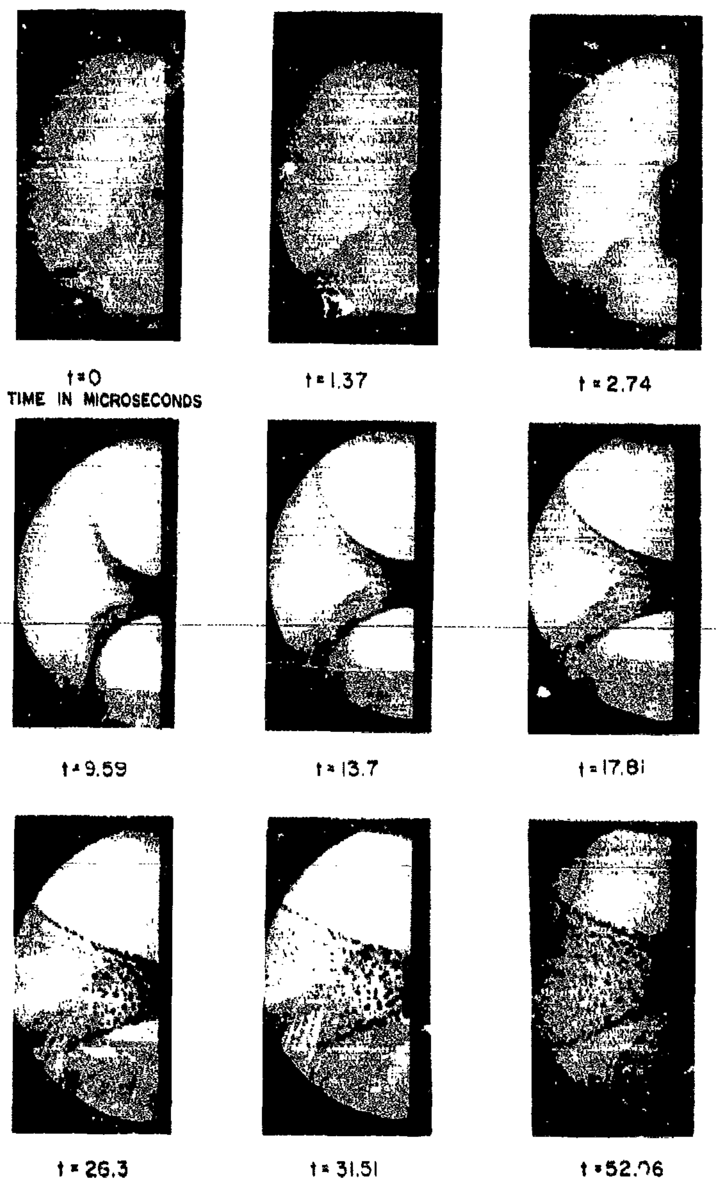


CRATER SIZE DEPENDENCE ON YIELD STRENGTH

FIGURE 2



66 FT. HYPERBALLISTICS RANGE NO. 2
FIGURE 3



A SEQUENCE OF PICTURES OF A $\frac{1}{4}$ INCH ALUMINUM SPHERE IMPACTING A 7075-O ALUMINUM TARGET AT ROOM TEMPERATURE. IMPACT VELOCITY=14,700 FT./SEC.

FIGURE 4

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Impact	IMPC	Dependence	DEPN		
Crater	CRAT	Variations	VART		
Size	SIZE	Heat	HEAT		
Temperature	TEMP	Mechanical	MECA		
Yield	YIEL	Target (properties)	TARGP		
Strength	STRN	Physics	PHYS		
Correlation	CORA	Aeroballistics	AERB		
Aluminum	ALUM				
Targets	TARG				
Spheres	SPHE				
Velocities	VELC				

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